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Simulation modelling and analysis of part and tool flow control decisions in a flexible manufacturing system

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ABSTRACT

This paper presents the details of a simulation study carried out for analyzing the impact of scheduling rules that control part launching and tool request selection decisions of a flexible manufacturing system (FMS) operating under tool movement along with part movement policy. Two different scenarios have been investigated with respect to the operation of FMS. In scenario 1, the facilities such as machines, tool transporter and part transporter are assumed to be continuously available without breakdowns, whereas in scenario 2, these facilities are prone to failures. For each of these scenarios, a discrete-event simulation model is developed for the purpose of experimentation. A number of scheduling rules are incorporated in the simulation models for the part launching and tool request selection decisions. The performance measures evaluated are mean flow time, mean tardiness, mean waiting time for tool and percentage of tardy parts. The results obtained through the simulation have been statistically analyzed. The best possible scheduling rule combinations for part launching and tool request selection have been identified for the chosen FMS.

1. Introduction

A flexible manufacturing system (FMS) is a production system in which groups of numerically controlled (NC) or computer numerically controlled (CNC) machines and an automated material handling system (MHS) work together under computer control. The system can simultaneously process medium-sized volumes of a variety of part types. FMS attempts to achieve both production flexibility and high productivity in order to meet the demands of today's competitive markets. A series of decision problems has to be addressed for the successful implementation of an FMS. These decision problems are classified as design, planning, scheduling and control [1]. Managing the flow of parts and tools is recognized as a critical issue in the operation of FMS. The versatile machines in FMS can perform a variety of operations when it is provided with the required tools. Increase in part variety means increase in number of cutting tool types. This requires a large tool mix and proper methods to plan, monitor and control tools, thus adding to the system cost. It is observed that tool-related costs constitute about 25–30% of the total costs associated with FMS applications [2]. Hence, proper planning and control procedures for tool management are needed for the efficient operation of FMS.

Generally, in most FMSs, operations of parts to be produced are allocated to machines and the corresponding tools are loaded into tool magazines of machines [3,4]. Parts are transferred from one machine to another according to the routing determined by the operations–allocation decisions. The operational policy for systems of this type is known as part moment policy. In some FMSs, tools required for processing a part but unavailable at a machine are transferred from another machine or the central tool store by a tool transport system. This operational policy is called tool movement policy. In this policy, the assignment of tools is not necessary at the beginning of a planning horizon or a production batch, since tools are delivered when they are needed, and, therefore, parts remain on the same machine until the required machining is completed. This policy is possible when the system is equipped with fast tool delivery devices and an efficient tool control model. This leads to the dynamic sharing of tools by machines. Technological developments in tool transport systems and shop floor information systems make this feasible [5,6]. Sharing of tools by machines virtually increases the capacity of tool magazines and eliminates the movement of parts from machine to machine in searching for tools. In such a tool-sharing environment, when the required tool is not available, a machine places a request for tool. If there are more than one tool requests at a particular instant, then appropriate tool request selection rules are used for selecting the request to be met. Accordingly, the tool is transferred to the required machine. Tool-sharing policy minimizes the total number of tools in the system and maximizes tool utilization.

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Several researchers like Stecke and Solberg [7], Shanker and Tzen [8], Berrada and Stecke [9], Mukhopadhyay et al. [10,11], Mukhopadhyay and Sahu [12], Nayak and Acharya [13], Tiwari and Vidyarthi [14], Kumar and Shanker [15], Rai et al. [16], Srinivas et al. [17] and Chan and Chan [18] have studied the problems of allocating operations and their associated tools under the part movement policy. However, there is relatively less number of reported research works on the decision problems under the tool movement policy. Gray et al. [19] present a review of tool management issues concerned with the operation of automated manufacturing systems. Elmaraghy [20] reports on a simulation study for the sharing of tools between the machine tool magazine, intermediate tool magazine, intermediate tool storage and central tool storage. The objectives considered include minimization of the distance traveled by the tool transporter, minimization of machine idle time, maximization of equipment utilization and minimization of tool redundancy. Using simulation to study the feasibility of tool sharing in an FMS, Gaalman et al. [21] show that tool sharing created savings on the overall cost of FMS. A look ahead policy is used to determine both the requirement of tool at machine center and the availability of tool before the actual operation takes place. Machine idle time due to non-availability of tools is used as a measure to study the effect of tool sharing and number of tool replications. Han et al. [22] present a mathematical model for tool loading with the objective of maximizing throughput. Heuristics have also been suggested and the performance of the heuristics was evaluated using a simulation model. Kashyap and Khator [23] use a simulation model to analyze the impact of tool-sharing rules on makespan and transporter utilization. Mohamed and Bernardo [24] have analyzed the interface between tool planning and the FMS loading and routing decisions. It is shown that tool policy has a pronounced effect on the flexibility and the planned makespan of an FMS. Koo et al. [25] have considered the tooling problem under dynamic tool assignment policy. They present an open queuing network-based model to predict the tool-requirement levels. Gougar et al. [6] provide a study of the application of ultra fast material transfer system for tool delivery where cutting tools are delivered to and from machines instantaneously from a central tool storage area. They suggest that eliminating redundancy in cutting tools and eliminating tool magazines at individual machines can offset the cost of such a system. Fathi and Barnette [26] deal with the problem of scheduling a set of parts with given processing times and tool requirements on identical parallel machines. Three heuristic procedures are proposed for solving the problem; the local improvement approach, the list processing approach and the constructive approach. Their computational study shows that the local improvement approach and the constructive approach tend to perform better, especially in situations where the tool-requirement matrix has an apparent structure. Lee et al. [4] present an integrated model that performs operation sequence and tool selection simultaneously with the objective of minimizing the tool waiting time. Buyurgan et al. [2] propose a novel approach utilizing the ratio of tool life over tool size (L/S), for tool selection and allocation. The proposed method selects tool types with high L/S ratios by considering tool alternatives for the operations assigned to each machine.

This paper presents the salient details of a simulation study conducted for investigating the effect of scheduling rules that control part launching and tool request selection decisions of an FMS operating under tool movement along with part movement policy. Two scenarios have been investigated with respect to the operation of FMS. Scenario 1 deals with failure free FMS. Scenario 2 considers failure prone FMS wherein the machines, tool transporter and part transporter are subject to failures. Discrete-event simulation models have been developed for the purpose of experimentation. The performance measures evaluated are mean flow time, mean tardiness, mean waiting time for tool and percentage of tardy parts. The results obtained through the simulation have been systematically analyzed. The best possible scheduling rule combinations for part launching and tool request selection have been identified for the chosen FMS.

In the FMS operation under tool movement policy, researchers have considered FMSs consisting of identical machines with tool sharing among the machines. It is assumed that each part is fixed to one machine throughout its total processing time and only the tools are transported to perform different operations on the part. However, in many cases, a part may need to visit more than one type of machine for its processing requirements. The FMS environment considered in the present study denotes such a situation where part movement and tool movement are involved. Further, system disruptions such as failures of machines, tool transporter and part transporter are also considered in the simulation studies. The simulation modelling and analysis of the FMS operating under these characteristics is a novel contribution to the literature.

The rest of the paper is organized as follows. Section 2 provides the approach adopted in the present study. The details of the configuration of the FMS chosen for experimentation are presented in Section 3. In Section 4, the salient aspects of the simulation models developed are described. This section also includes the description of the scheduling rules for part launching and tool request selection decisions. Section 5 presents the details of the experimentation. The results and analysis are provided in Section 6. Conclusions are presented in Section 7.

2. The approach adopted

The problem identified for investigation is controlling the flow of parts and tools in an FMS operating in a tool-sharing environment. Basically, the decisions considered are as follows:

(1) Part launching: this involves selecting the part to be loaded on a pallet at the input end of FMS for subsequent launching into the system.
(2) Tool request selection: in a tool-sharing environment, tools required for a part but unavailable at a machine are transferred from another machine or the central tool store (tool crib) by a tool transport system. If there are more than one tool requests at a particular instant, then a tool request selection rule is used for selecting the request to be met. Accordingly, the tool is transferred to the required machine.

For each of these decisions, different scheduling rules have been used in the present study.

Two different scenarios have been considered with respect to the operation of FMS as follows:

Scenario 1: failure free FMS in which the machines, tool transporter and part transporter are free from failures.

Scenario 2: failure prone FMS wherein the machines, tool transporter and part transporter are subject to failures.

For each of these scenarios, a discrete-event simulation model is developed.

3. FMS configuration

A realistic FMS configuration has been conceived for a detailed study and analysis. The factors suggested by Schriber and Stecke [27] for configuring FMS for simulation model-development have also been taken into account. The various aspects pertaining to the